

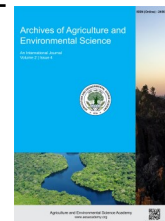


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REVIEW ARTICLE



A review on yield response to nitrogen, potassium and manure applications in potato (*Solanum tuberosum* L.) production

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ABSTRACT

Potato productivity has stagnated and remained low due to, among other causes, increasing soil infertility and poor nutrient management strategies. To avert this situation, it is essential to have a better understanding of potato response to nitrogen and potassium nutrients. Like other crops, potatoes require an adequate and balanced supply of nutrients for better growth and tuber yields. To achieve that, it is essential to conduct an extensive soil analyses for the entire farm. However, this process is expensive for most resource-constrained farmers. Moreover, the current recommendations used in the region are generic and focuses more on nitrogen than potassium. Hence, there is a need to focus on readily and freely available information for enhanced decision making. The assumption that the soils in the region are fertile and can supply adequate potassium is no longer valid, and now necessitates more actions such as adopting integrated soil fertility and precise application of nutrients within the 4R principles. All these aspects are well covered in this article. We believe the information presented in this manuscript is valuable and give a better foundation for future research and recommendations in potato production.

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INTRODUCTION

Potato (*Solanum tuberosum* L.) is one of the most important crops in East Africa with the potential to abate hunger and increase the economic status of farmers due to its high yield per unit area of land compared to maize (UARC, 1990). According to the International Potato Center (CIP) (2008), one hectare of potatoes can yield 2-4 times the food value of grain crops. In East Africa, the main potato producing zones include Njombe, Iringa, and Mbeya in Tanzania; Mt. Kenya, Central, Central Rift, and North Rift regions in Kenya; Kabale and Kisoro districts in Uganda; Rubavu, Musanze, Nyabihu, and Burera in Rwanda (Otieno, 2019a; FAO, 2020). Over the past decade, production has varied between 28,158 to 181,209 tons in Burundi, 1,335,883 to 2,915,067 tons in Kenya, 719,006 to 1,789,404 tons in Rwanda and 1,235,041 to 1,767,536 tons in Tanzania (FAOSTAT, 2019). Additionally, despite their high food value and economic im-

portance, potato yields have remained low amidst an ever-increasing population that demands more food in the region. Currently, potato yields have stagnated between 5 and 9 tons per hectares compared to the achievable farmer yields of about 20 tons per hectare (Otieno, 2019a). The low yields could be attributed to soil infertility, improper use of fertilizer, foliar pests and diseases, use of poor quality tuber seeds and low yielding varieties, untimed weed control, and within-season droughts (Schulte-Geldermann, 2013; Muthoni and Kabira, 2016; Otieno, 2019b; Okeyo et al., 2019; Mugo et al., 2020).

Unlike other tubers and root crops, potatoes are sensitive to changes in nutrient levels (especially Nitrogen (N), Phosphorous (P), and Potassium (K)) that affect the vegetative phases, severely reduce tuber yields at the bulking stage negatively impacting the quality of tubers. Achieving optimum nutrient requirements by smallholder farmers has always been challenged by inadequate financial resources to perform soil

analysis and purchase the recommended quantities of fertilizers. In addition, the current crop response data have not been well aggregated to simplify recommendations which has led to blanket recommendations that omit essential nutrients in the package despite heavy nutrient mining that has occurred for years across the East African soils. To assist resource-constrained farmers apply better and affordable fertilizer rates, detailed research is needed to identify optimal nutrient combinations for application across different soil fertility status.

Based on this background, this work aimed at presenting in-depth findings on (a) the current state of soil fertility management for potato production in Eastern Africa and (b) potato tuber yield response to nitrogen and potassium nutrients application in different soil types and fertility indices for future research and better recommendations. This research also accounts for the 4R nutrient use principles described under the 4R Nutrient Stewardship: Right fertilizer source at the right rate, at the right time, and in the right placement (Bruulsema *et al.*, 2012). This work is purely based on secondary data drawn across various studies applicable in East Africa. The absolute yield responses were expressed as the percentage change above the non-treated yields. Each trial season was treated as an independent trial set of data. For this research, we used a total of 30 peer-reviewed publications on tuber response to N and 18 peer-reviewed publications on tuber response to K applications. The percentage increases and nutrient rates were then used to draw the two polynomial order curves for presentations. Each curve was described in three segments: the steep phase - where the curve increases at an increasing rate; the less steep phase - where the curve increases at a decreasing rate; and the relatively flat phase - where any additional fertilizer rates are not causing any significant increase in yield.

The current state of soil fertility management for potato production in Eastern Africa

Based on the reported high nutrient removal rates per unit weight of harvested tubers, farmers need to supply adequate fertilizer quantities to replenish the lost nutrients. Various organic and inorganic fertilizer rates and compositions have been recommended across the region. In Kenya, the Kenya Agricultural and Livestock Research Organization (KALRO) Tigoni potato research center recommends that nitrogen and phosphorus in the form of diammonium phosphate (18:46) be applied at a rate of 500 kg ha⁻¹ (KALRO, 2008; Gildemacher *et al.*, 2009). In Ethiopia, the government recommends N and P to be applied at 111 kg and 40 kg per hectare, respectively (Girma *et al.*, 2017). In Tanzania, a rate of between 150 and 300 kg NPK-23:10:5 has been found to increase yields between 15-19 t ha⁻¹ with better returns on investment (Shaaban and Kisetu, 2014). Application of 100 kg NPK-17 per hectare was reported to increase yields across 48 potato genotypes evaluated in Uganda (Namugga *et al.*, 2018). The above mentioned rates are commended for use across the entire region irrespective of soil type, current fertility status and cropping system. However, in

some cases, essential nutrients have been omitted from the package. For instance, recommendations for Kenya and Ethiopia do not include K nutrient despite its crucial importance in improving yields and qualities of tubers. This omission could be due to the perceived abundance of K in the soils across the region. Nevertheless, high nutrient mining has occurred, with current research reporting a decline in the levels of nutrients (Otieno, 2019c). Therefore, the current compositions and rates need to be re-evaluated based on the responses and soil fertility status for a better return on investment.

Potato tuber response to nitrogen and potassium fertilizer application

Potatoes, just like any other crops, require an adequate and balanced supply of nutrients for better growth and production. Compared with other crops, potatoes have a high demand for N and K nutrients. In terms of nutrient mining, potatoes remove about 4 kg N and 6.5 kg K, per ton of tubers harvested (Beukema and Van der Zaag, 1990). A limited supply of N and K severely affects potatoes at the vegetative and tuber bulking stage, significantly reducing tuber yields. Hence for optimal production, soils must be replenished with N and K. Importantly, the demands for these nutrients vary depending on the stage of growth. For instance, the stage of highest macronutrient demand by various potato cultivars is during initial tuber bulking and varies between 42 to 70 days after planting (Fernandes *et al.*, 2011). Factors that influence potato nutrient requirements include potential tuber yields, edaphic factors (e.g., soil temperature, texture, cation holding capacity, and pH), climatic factors (e.g., ambient temperature and rainfall), and biotic factors (e.g., pest and disease infestation) (Clarkson, 1985; Stark *et al.*, 2004).

Potato tuber response to nitrogen nutrient; Source, rate, time, and placement

Nitrogen is the highly used nutrient in terms of rates and frequencies of application than any other globally (Bowen *et al.*, 1999). The nutrient makes up the highest proportion of dry matter in plants compared to other nutrients - it forms 3-4% of dry matter (FAO, 1978; Crop Nutrition, 2019). At the critical bulking stage, the crop's daily N requirement is about 4.5 kg ha⁻¹ (Haifa, 2019). At this critical bulking stage, the plants take up 40-50% of their seasonal N requirement (Stark *et al.*, 2004). At harvesting, about 20-25% and 75-80% of the plant's total N are contained in the vines and tubers, respectively (Stark *et al.*, 2004). This is because N plays essential roles in the formation of nucleic acids, protein, chlorophyll, enzymes, energy-transfer compounds, and regulation of crucial biochemical reactions in plants (Beukema and Van der Zaag, 1990; Leghari *et al.*, 2016; Crop Nutrition, 2019). During crop growth, nitrogen is taken up from the soil mainly in two forms; nitrate (NO₃⁻) and ammonium (NH₄⁺) ions. Potatoes significantly respond to N application, and this response is influenced by soil characteristics (e.g., baseline soil fertility status and soil type) and general crop management practices.

Based on meta-analysis, we saw potato yields increasing steeply with an increase in N application up to approximately 150 kg N per hectare before beginning to increase at a reducing rate towards 250 kg N per hectare (Figure 1). The increase rate in yield is even much slower from this point and appeared to plateau from 300 kg N per hectare rate (Figure 2). This trend has been reported under different soil fertility levels across various potato-producing countries namely Ethiopia (Zelalem *et al.*, 2009), India (Sriom *et al.*, 20017), and New Zealand (Craighead and Martin, 2003). According to Ruža *et al.* (2013), a better N utilization coefficient is achieved at 120 kg N ha⁻¹. Adhikari (2009) also reported and recommended N to be applied at 150 kg ha⁻¹ for optimum production. Studies by Kumar *et al.* (2007) and Fontes *et al.* (2010) have proved that the agronomic N use efficiency of potato decreases linearly with increasing N application above 150 kg ha⁻¹. In terms of quality, Sanderson and White (1987) found that at N rates above 150 kg ha⁻¹, yield, tuber size, and specific gravity are detrimentally affected. Therefore, the critical rate could be set at 150 kg N ha⁻¹ (Goffart *et al.*, 2008; Ruža *et al.*, 2013). However, slight deviations could be observed in some cases. For instance, in India, the highest agronomic and uptake efficiencies were recorded at 160 kg N per ha⁻¹ (Kumar *et al.*, 2009).

The source of N nutrient seems not to have a direct influence on tuber yield. According to Gathungu *et al.* (2000), the use of urea, calcium of ammonium nitrate (CAN), and ammonium sulfate nitrate (ASN) as different sources of N did not show significant direct influence on tuber yields, and any differences observed could have been due to other factors. These factors may include differences in the number of tubers per plant, time of N application, and rates of N losses. Also, Sanderson and White (1987) concluded that urea and ammonium nitrate differentially influence the growth responses of potatoes and that these differences are influenced by N rate, cultivar, location, and climatic conditions, but not the source. Based on these findings, N rates

ranging from 50 to 150 kg N ha⁻¹, depending on the financial status of the farmers, could be recommended for better yields, quality, and return on investment across various soil fertility gradients. Rates above 150 kg ha⁻¹ increase potato yields though at a decreasing rate up to about 250 kg ha⁻¹ - a rate that seemed to maximize the yield potential of a variety though may not be profiting. To allow for better recommendations, farmers should test their soils for available N and organic matter contents and the capacity to release the required amounts of N and adjust fertilizer rates appropriately. Proper timing of N application is also critical. During topdress application, N should be applied in splits to reduce losses from leaching, volatilization, and erosion processes. Split application of N also ensures that the nutrient is made available only when needed, thereby increasing N-use efficiency. The two critical stages for N application are at planting for early establishment to boost growth and at tuber initiation to maintain the high N concentration required for proper tuber development. At all times, N-based fertilizers should be supplied on moist soils and covered to reduce losses.

Potato tuber response to potassium application; Source, rate, time, and placement

Potassium (K) is a very important nutrient in potato production because it plays vital role during growth, tuber development, and tuber quality. Additionally, K plays a vital role in several physiological processes such as photosynthesis and translocation of photosynthates, stomata regulation and transpiration, and activation of plant enzymes (Thompson, 2010). Potassium enhances N uptake and protein synthesis resulting in better foliage growth (Marschner, 1995). Also, it enhances root permeability and water uptake and, hence, improving water use efficiency (Mehdi *et al.*, 2007). Combining K and N increases the foliage and leaf area index (Marton, 2001; Saha *et al.*, 2001).

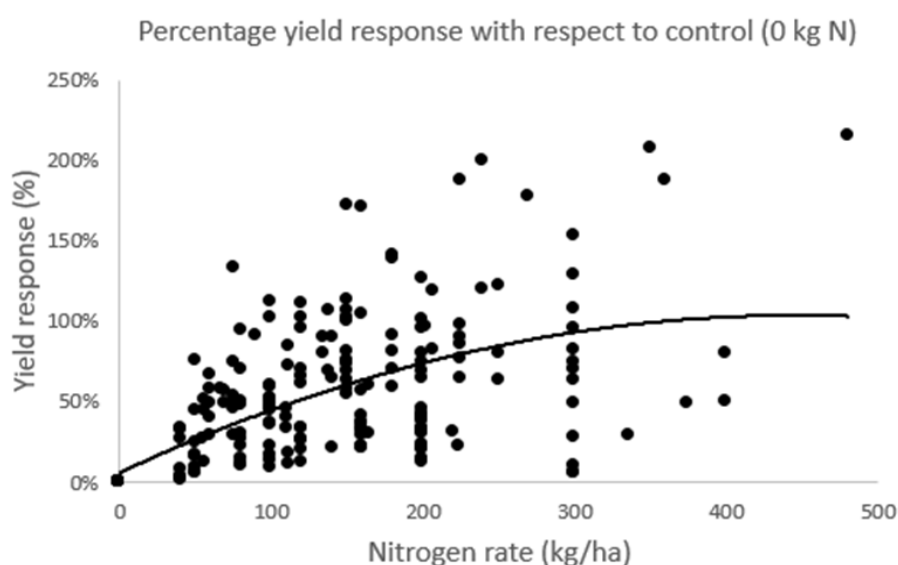


Figure 1. Shows a graphic presentation of potato tuber yield response to different rates of nitrogen applications. The absolute yield responses were expressed as the percentage change above the non-treated yields. Each trial season was treated as an independent trial set of data. In total, 30 publications were considered for tuber response to N applications. On average, the yields increased steadily at an increasing rate up to about 150 kg N ha⁻¹ before starting to increase at a decreasing rate towards 250 kg N ha⁻¹.

Adequate supply of K is believed to help in improving the color of the final fried potato product (Perrenoud, 1993). The demand for this nutrient varies depending on the stage of plant growth and soil fertility status. At the critical bulking stage, daily K requirements could vary, reaching as high as 6 kg ha^{-1} (Haifa, 2019). At this stage and under optimal supply, potato plants would take up 40-50% of their seasonal K requirement (Stark *et al.*, 2004). However, most of this nutrient is not going into yield production as potatoes have tendencies to consume more K nutrients than they need. From the analysis, the tuber yields increased steadily up to $150 \text{ kg K}_2\text{O}$ per hectare before beginning to increase at a declining rate peaking at approximately $300 \text{ kg K}_2\text{O ha}^{-1}$ (Figure 2). A similar trend was confirmed by Allison *et al.* (2001), Craighead and Martin (2003), Moinuddin *et al.* (2005), Zelelew and Ghebreslassie (2016). In order to maximize yields and have high-quality tubers, researchers across different soil fertility gradients have recommended that potassium application should not be made at rates exceeding $200 \text{ kg K}_2\text{O ha}^{-1}$ (Perrenoud, 1993; Allison, 2001; Al-Moshileh and Errebi, 2004; Karam *et al.*, 2011; Shunka *et al.*, 2016). From the response curve, up to 150 kg ha^{-1} should be economical. This rate also guarantees better quality tubers (Khan, 2010). This rate yields significantly similar tubers to those achieved from using $200 \text{ kg K}_2\text{O ha}^{-1}$ (Khan *et al.*, 2010). Any application rate between 50 and 100 kg ha^{-1} has the steepest response gradient, possibly maximizing the profit for farmers. Above $150 \text{ kg K}_2\text{O ha}^{-1}$, researchers found decreased vitamin C content. Smith (1977) in a three-year experiment in Poland, reported increased vitamin C with $50 \text{ kg K}_2\text{O ha}^{-1}$ application, no effect at $100 \text{ kg K}_2\text{O ha}^{-1}$, but reductions at rates above $150 \text{ kg K}_2\text{O ha}^{-1}$. According to Stark *et al.* (2004), if K uptake is excessive, surplus K is translocated to the tubers, causing increased tuber water absorption and decreased specific gravity.

The effects of K sources on tubers tend to report mixed impacts on potato production. Malakouti *et al.* (1995), Stark *et al.* (2004), and Gunadi (2016) reported that K-sulphate (K_2SO_4) was

superior to K-chloride (KCl) in terms of tuber yields. However, Bruchholz (1974), Panique *et al.* (1997) in Imas (1999), Davenport and Bentley (2001), and Kumar *et al.* (2007) reported similar yield effects due to these K sources. Due to mixed outcomes, more research is needed to understand yield response due to different sources of K nutrients. Nevertheless, for crisping potatoes, Kumar *et al.* (2007) suggested that K-sulphate is more suited than K-chloride, as it increased crisp yield and decreased crisp oil percentage. In terms of timing and method of K application, just like phosphorus, potato crops benefit more when the application is made either before or at the time of planting. However, for increased efficiency and reduced losses, split applications could be recommended. This application should be done early but not later than 30-60 days before planting (Stark *et al.*, 2004; Gunadi, 2016; Otieno, 2019a). In general, K topdressing should be done before row closure. Consistently higher yields were recorded when K was applied during bulking than when applied at the tuber initiation stage (Karam *et al.*, 2011). This response illustrates that a larger proportion of the recommended K rate should be top-dressed during this stage when carrying out a split application of K fertilizers. Based on this study, potassium should be applied at rates not more than $200 \text{ kg K}_2\text{O ha}^{-1}$. These fertilizers should be placed 5 cm away from the seed tubers and thoroughly mixed with soil. Under split application, fertilizers should be supplied at planting and at any time before row closure.

Potatoes tuber response to manure/compost application

Potatoes require soil organic matter for nutrient supply, improved nutrient use efficiency, and soil water conservation. The use of manure in potato production is common in East Africa and has been confirmed by Tadesse *et al.* (2017) and Mugo *et al.* (2020). The benefits of using manure/compost include nutrient source, improvement of soil pH, increased soil organic matter, soil organic carbon, and crop yields (Linus *et al.*, 2004; Muthoni and Kabira, 2011; Otieno *et al.*, 2018).

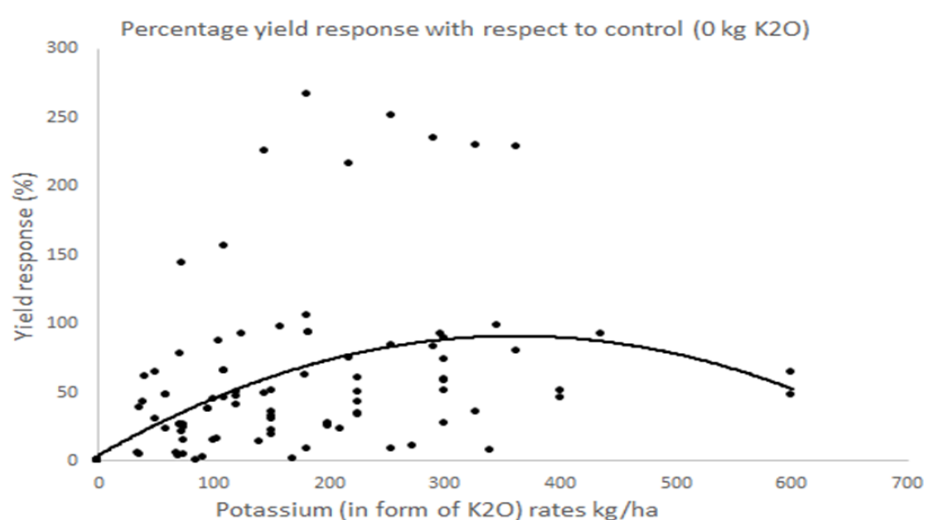


Figure 2. Shows a graphic presentation of potato tuber yield response to different rates of phosphorus. The absolute yield responses were expressed as the percentage change above the non-treated yields. Each trial season was treated as an independent trial set of data. In total, 18 publications were considered for tuber response to K applications. The yields increased steadily up to 150 kg ha^{-1} before beginning to increase at a decreasing rate towards 200 kg ha^{-1} . The response peaked at about $300 \text{ kg K}_2\text{O ha}^{-1}$.

The use of manure/compost also eliminates to a great extent the potential of having nutrient toxicity commonly caused by excess application of chemical fertilizers. The use of high-quality manure has been found to yield better than the use of inorganic. In fact, of all field crops, potatoes have the best response to farmyard manure (Lutaladio *et al.*, 2009). Girma *et al.* (2017) reported a significant improvement in tuber yields and nutrient-use efficiencies with the sole application of farmyard manure at 28.8 t ha⁻¹ than with the use of inorganic fertilizers. Mnalku and Yenieneh (2016) reported the highest total tubers yield (25.87 t ha⁻¹) with farmyard manure rates as low as 7.5 t ha⁻¹ compared to inorganic fertilizer (20-24.69 t ha⁻¹). Achiri *et al.* (2018) also reported statistically similar yield biometric parameters of potatoes between the application of 3.15 tons of poultry/pig manure, 356 kg NPK-15, and 650 kg NPK- 11:11:22 per hectare in Brouham, West Region Cameroon. However, despite being common in the region, there is no clarity on manure rates recommended for potato production. The use of a wide range of manure rates could be attributed to quality issues- the higher the quality the lower the application rates. Also, it could be due to lack of standard recommended rates by national research centers; hence, farmers applying as much as they could get. However, Lutaladio *et al.* (2009) recommended using well-composted farmyard manure at a rate of 10 t ha⁻¹ or more, if available, for developing countries. The quality of manure is influenced by factors such as production methods, raw materials used, the period, and storage methods. Due to the slower release of nutrients in the first season of application, it is advisable to apply both manure and inorganic fertilizers together. Otherwise, application of manure should be made at least 2-3 weeks before planting. Well-decomposed manure could be applied together with fertilizer, a method recommended in realizing better nutrient use efficiencies. Under such circumstances, inorganic fertilizer rates could be reduced accordingly. Combining fertilizers with manure has been reported to improve soil health, give a better nutrient use efficiency, yield response, and return on investment than inorganic fertilizer alone (Abdulkadi *et al.*, 2017; Girma *et al.*, 2017; Isreal *et al.*, 2018; Cui *et al.*, 2018). Hence, it should always be recommended for combined application with chemical fertilizer especially in situations where farmers are unlikely to supply the recommended fertilizer rates.

Conclusion and recommendations

Crop response to fertilizer application is highly influenced by the soil fertility status and the capacity to release these nutrients. Potatoes, like other crops, require adequate and balanced supply of nutrients. All these nutrients need to be supplied every season for optimal production. For improved recommendations, soil testing is vital in ensuring that only deficient nutrients are supplied in the right quantity at the right time. Soil testing for N and K nutrients must be done before making any blanket recommendations. Nitrogen should be applied at rates not more than 150 kg N ha⁻¹. The luxury consumption of K by potatoes

makes it a complicated nutrient to make optimal recommendations. Based on the data available, the rate of K applicable should not exceed 250 kg ha⁻¹, with a steeper gradient at about 150 kg ha⁻¹. For better response and sustainability in production, farmers should strive to apply better quality manure if available. At least 10 t ha⁻¹ of well-decomposed manure is recommended. This rate could vary depending on the quality. Manure could be used solely without inorganic fertilizer if the quality is good or in combination with inorganic fertilizer.

Conflict of interest

The authors have done this research and wrote the article and there is no conflict of interest including any financial, personal or other relationships with other people or organizations.

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